



Small Satellite-sized Hypersonic Inflatable Decelerators for Interplanetary Science Missions

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Introduction

To take full advantage of our increased access to space, through reduced launch costs that ridesharing opportunities present, innovative and lower cost options for interplanetary exploration are needed. Capitalizing on the technology miniaturization trends and the SmallSat class of vehicles could provide advancements for interplanetary space exploration.

Presented here, are the results of a feasibility study conducted during an internship at NASA Langley Research Center that explored the use of a SmallSat-sized Hypersonic Inflatable Aerodynamic Decelerator (HIAD) to enable interplanetary orbital science missions via aerocapture.

Aerocapture

Interplanetary travel

- Higher arrival velocities
- Higher orbit insertion costs using fully propulsive methods

Aerocapture

- Uses a planet's atmosphere to reduce propulsive burn requirements
- Requires an aeroshell

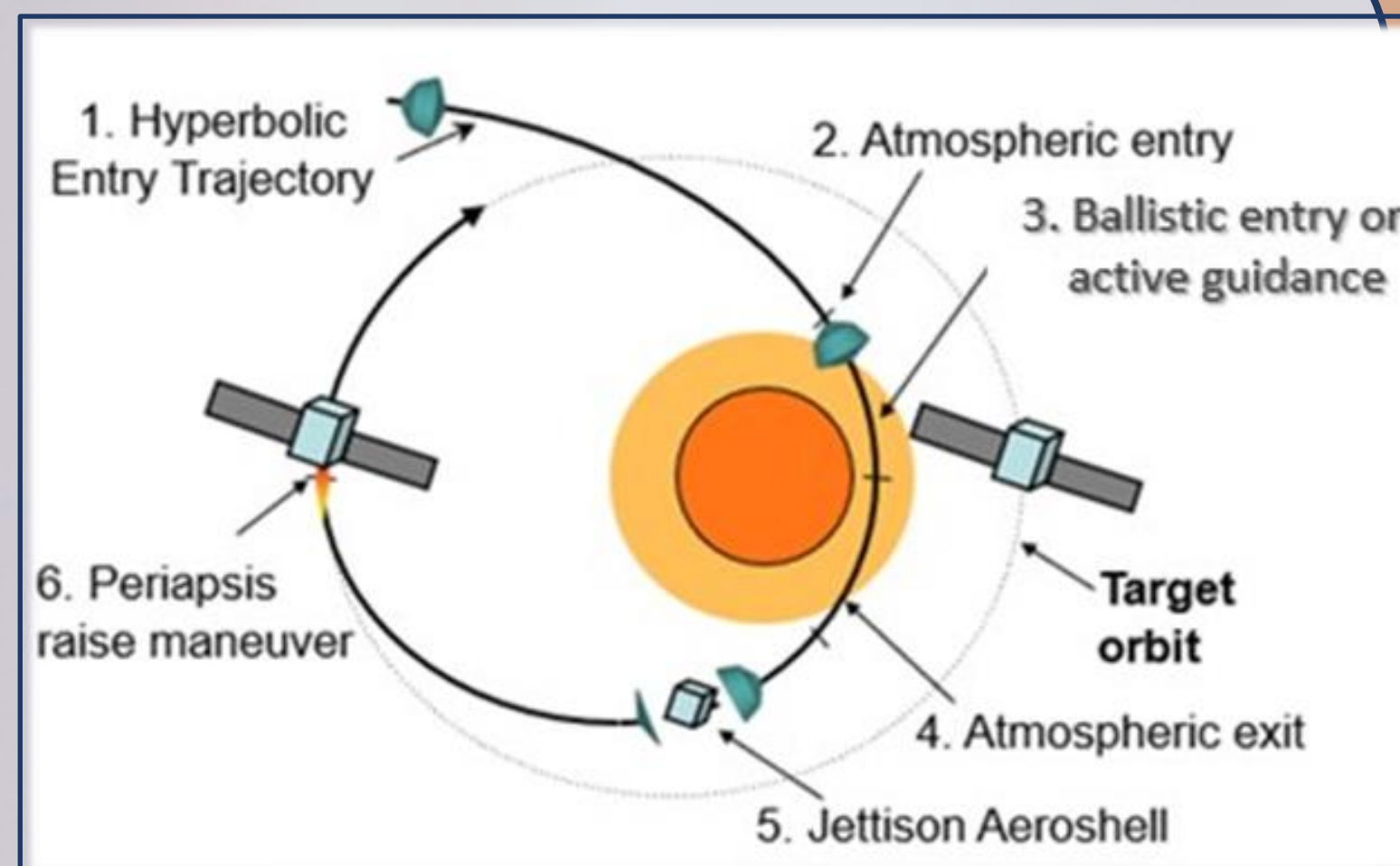


Figure 1: Typical aerocapture maneuver. Credit Ref [1]

HIAD Aeroshell

Rigid Aeroshells

- Mass and space is limited due to rigid geometry.

HIAD – Hypersonic Inflatable Aerodynamic Decelerator

- Is an inflatable aeroshell with a stacked toroidal design under active development by NASA.
- Conforms to launch vehicle size constraints when stowed.
- Delivers a larger frontal drag area than rigid aeroshells when deployed.

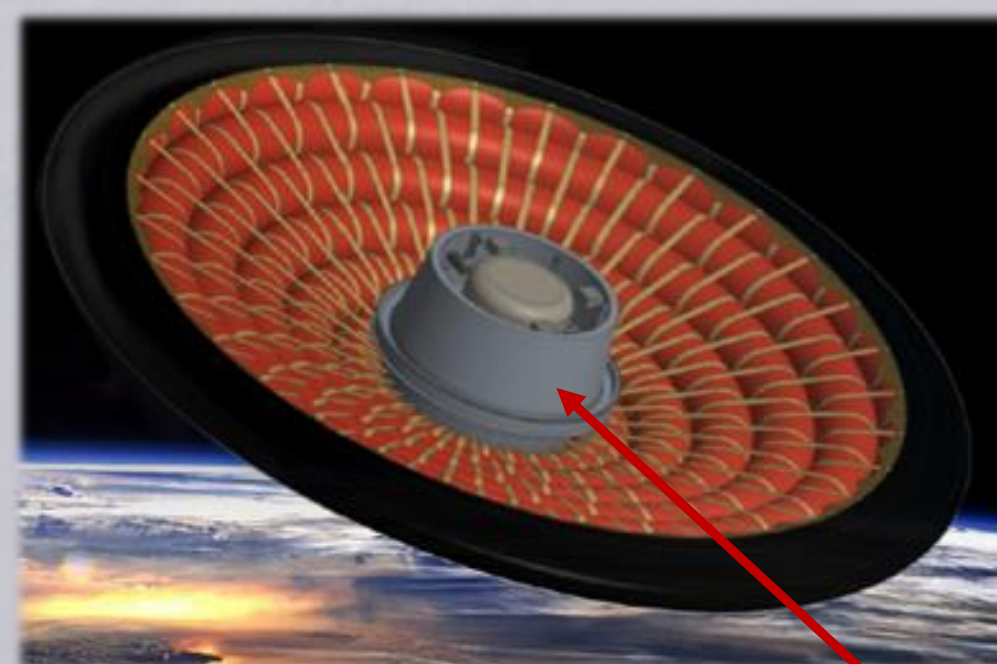


Figure 2: Deployed HIAD

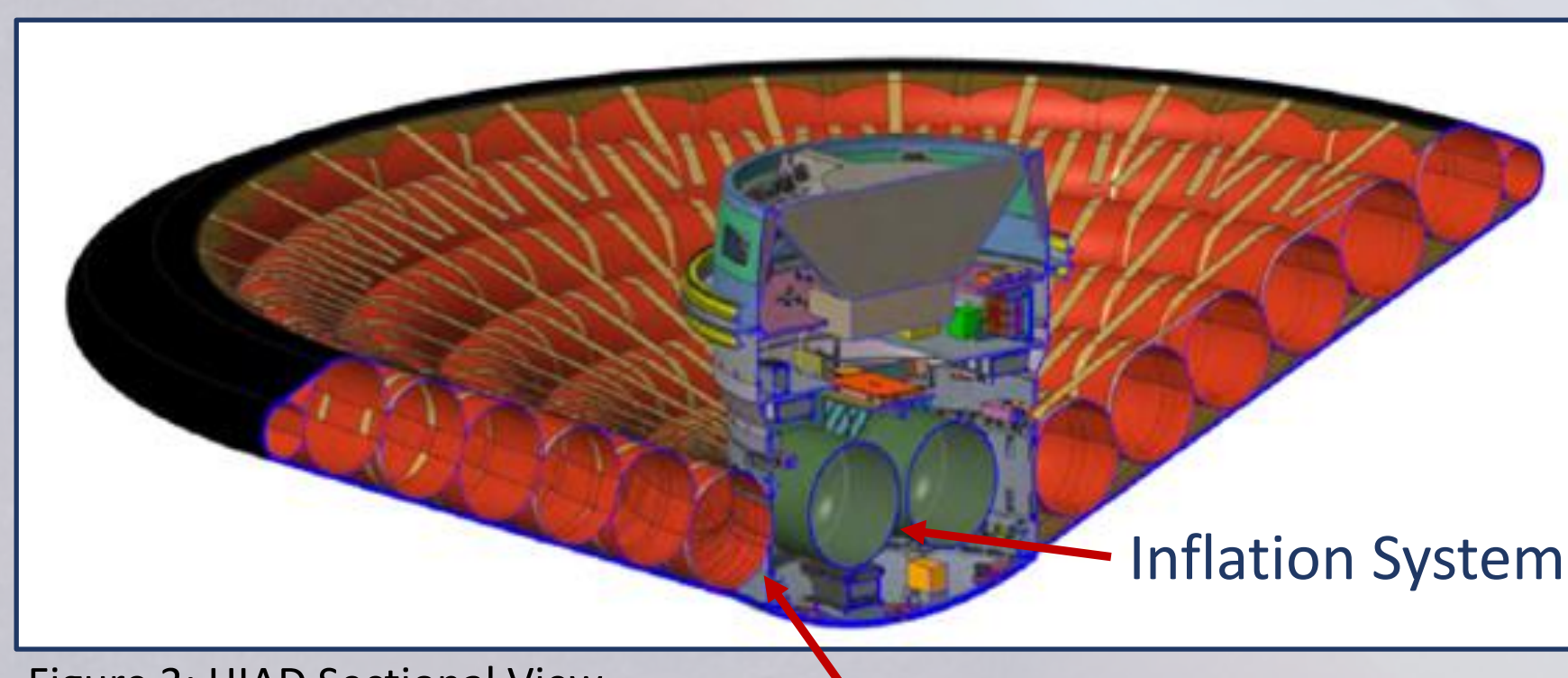


Figure 3: HIAD Sectional View

Science Payload

HIAD Forward Segment

HIAD graphics: LOFTID fact sheet, NASA.gov

Feasibility Study

Small satellite-sized HIADs

- Can they be used for interplanetary aerocapture missions at Mars, Venus, and Earth?

Std. ESPA Heavy [2]

Max mass – 450 kg
Vol. – 24 x 28 x 38 in

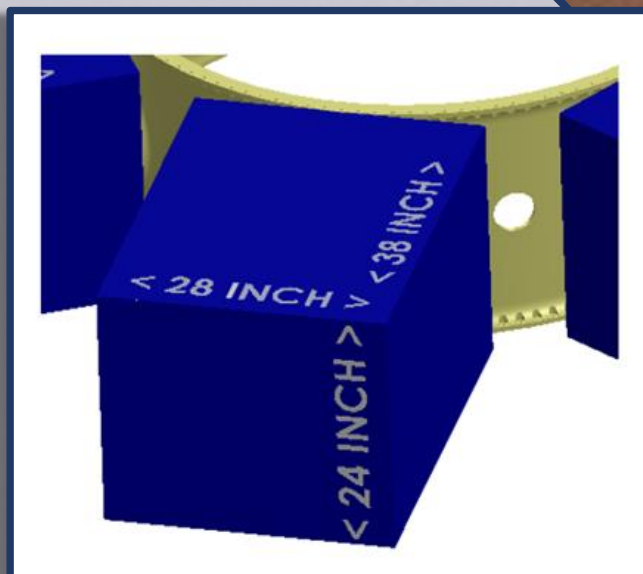


Figure 4: Volume constraint for Std. ESPA

Candidate SmallSat HIAD sizes

- Constrained by secondary payload adapter volume and mass specifications.
- Identified candidate sizes – 0.5m, 1m, 1.5m, 2m, and 2.5m diameter designs.
- LOFTID's 6-meter HIAD design was used as a basis for scaling.

Trajectory Performance Analysis - Simulations

- Two limiting cases – Max Vehicle Mass and Thermal Protection Limits.
- Sensitivity study – Aerodynamic, Atmospheric, and Entry Condition dispersions.

Case 1 – Max Vehicle Mass

Case 1 - used a fixed vehicle mass of 450 kg for all SmallSat HIAD designs, which represented the mass of the HIAD plus a science payload and additional subsystems required for a mission. This was done to establish nominal behavior and performance metrics for comparison during the sensitivity analysis.

Simulation Scenario – For the HIAD 70° sphere-cone geometry, hyperbolic entry aerocapture scenarios targeting a range of circular orbits were evaluated at the destinations of Mars, Venus, and Earth assuming unguided ballistic entry.

- All nominal cases achieved orbit insertion

Design Sensitivities – The dispersion analysis identified significant entry condition sensitivities, indicating active guidance will be needed to insure desired insertion conditions.

Case 2 – Thermal Protection Limits

Heating Rate Feasibility Target

- Heating rate target - 75 W/cm² based on current Flexible Thermal Protection System limits (F-TPS)
- All heating rates from Case 1 were above this limit.

Heating rate reduction efforts

- Refined initial mass estimates* (Results summarized in Table 1)
- Entry velocity variation
 - Mars – none needed.
 - Venus - reduced from 11.5 to 10.3 km/s
 - Earth - reduced from 11.5 to 10.3 km/s to simulate an approach from a GTO - Geostationary Transfer Orbit.

Results -

The results of these efforts are shown in Figure 5. For Earth, the 1.5m, 2m, and 2.5m designs are within F-TPS limits. The 2.5m design for Venus is within limits, with the 2m HIAD showing marginal viability. While the 1m, 1.5m, 2m, and 2.5, designs were within the F-TPS limits for Mars.

* For more details on the study, please see reference [3].

Table 1: Summary of refined mass estimates. The initial mass estimate was obtained from direct scaling of the 6-meter LOFTID design.

Summary of Refined Mass Estimates		
HIAD design	Initial Estimate (kg)	Reduced Estimate (kg)
1m HIAD	105	38
1.5m HIAD	156	60.8
2m HIAD	202	85.4
2.5m HIAD	257	111.2

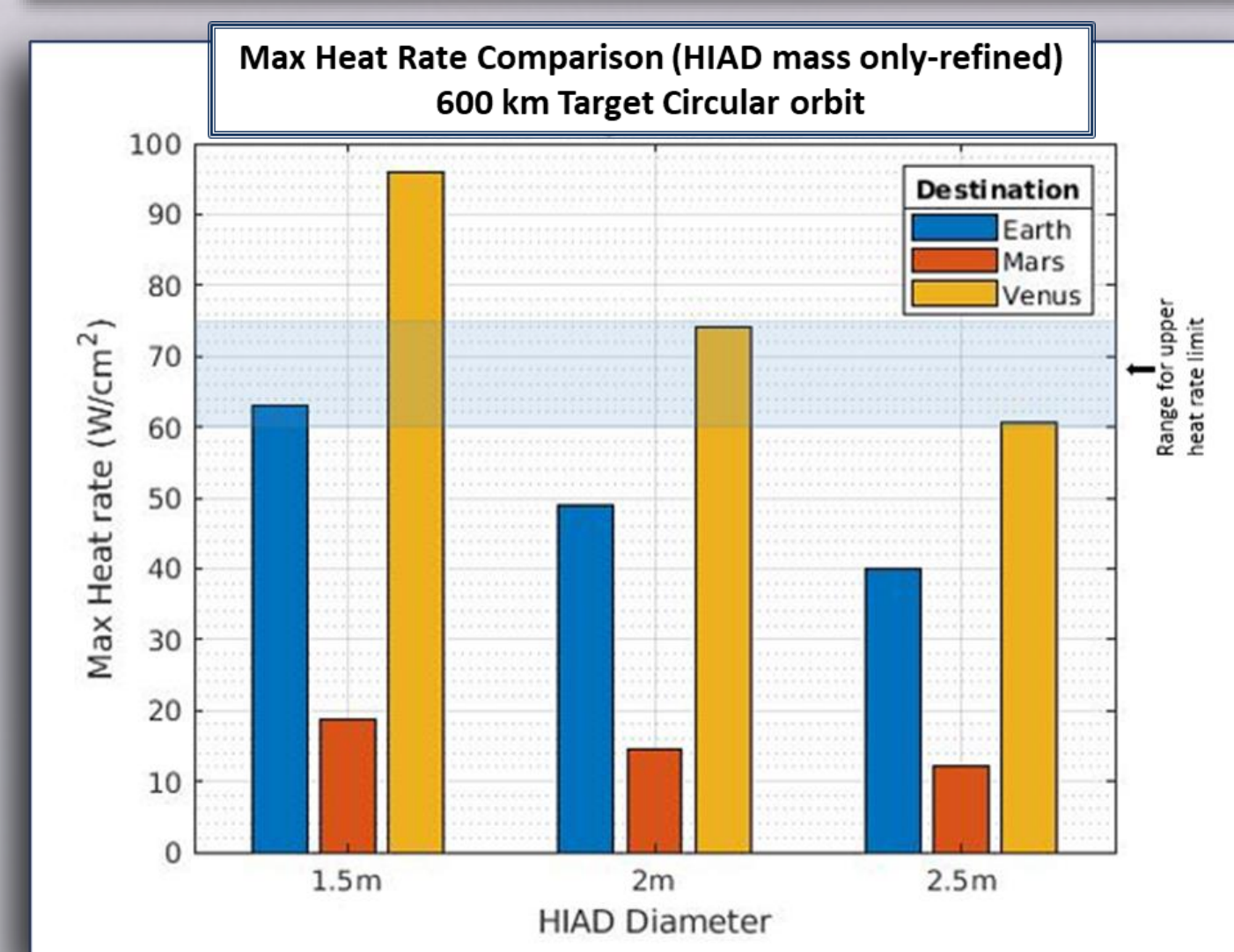


Figure 5: Maximum heat rate comparison of each HIAD using the refined mass and incorporating entry velocity variations.

Conclusion & Payload Capacity

Potential Payload Capacities were explored for Earth and Venus as a final exercise in this feasibility study. The results are summarized below. Figure 6 shows how the heating rates are affected by the addition of a payload, for the Earth case. Payload capacities for Mars are expected to be higher due to its thinner atmosphere.

Potential Payload Capacities:

For Earth-

1.5-meter HIAD: up to 14 kg
2-meter HIAD: up to 55 kg
2.5-meter HIAD: up to 149 kg

Venus – 2.5-meter: ~40kg

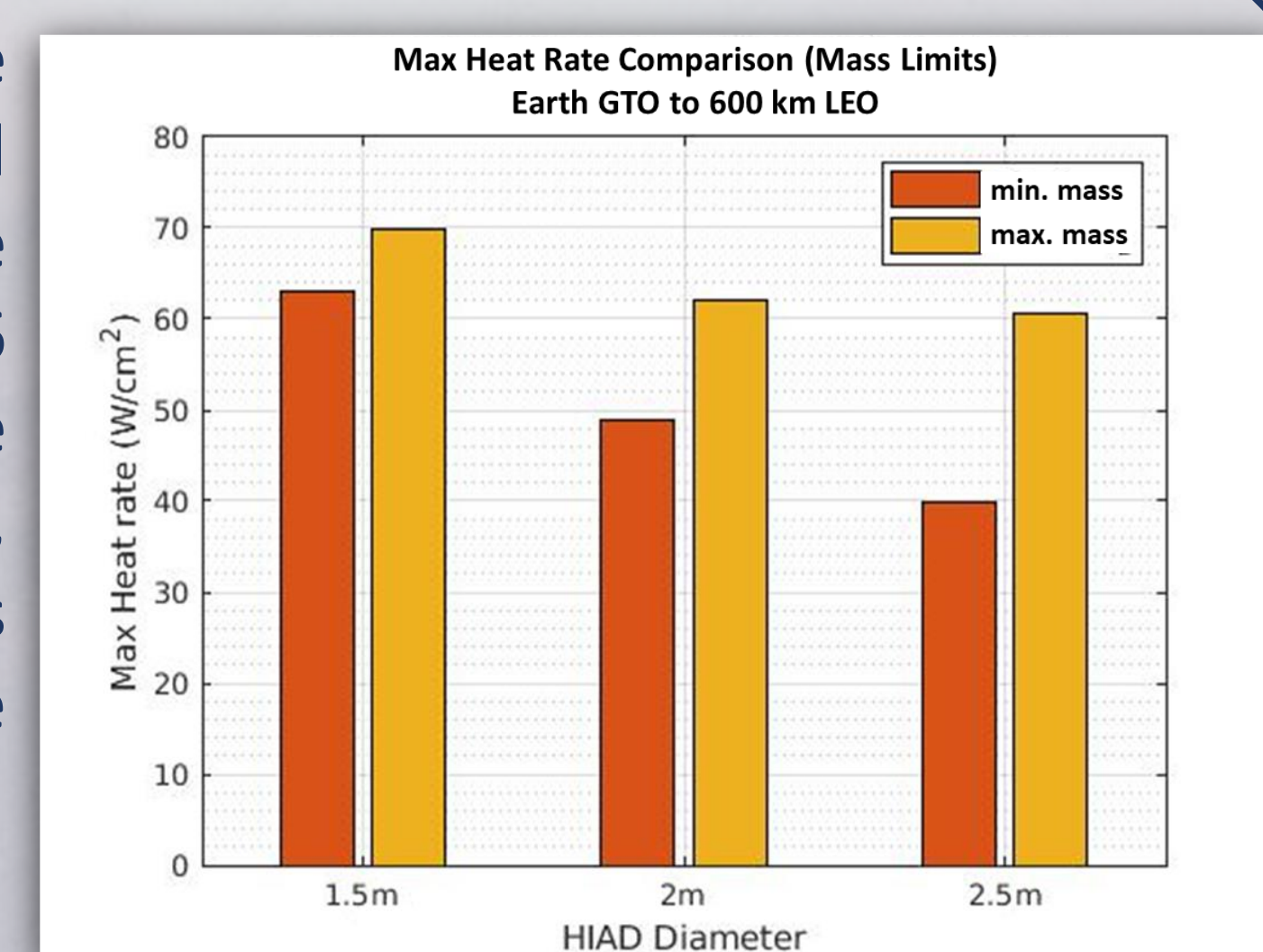


Figure 6: Maximum heat rate comparison of min. mass (HIAD only) and max. mass (HIAD plus a payload) for Earth

Conclusion:

These promising results suggest that SmallSat-sized HIADS are feasible options for interplanetary science missions and are worthy of further exploration.

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References:

- [1] Munk, M., and T.R. Spilker, "Aerocapture Mission Concepts for Venus, Titan, and Neptune," 6th International Planetary Probe Workshop, Atlanta, GA, 2008.
- [2] ESPA User's guide, MOOG Space and Defense Group, 2018.
- [3] Mann, S., Bowes, A., Deshmukh, R.G., Dutta, S., "Small Satellite-sized Hypersonic Inflatable Aerodynamic Decelerators for Interplanetary Science Missions", 36th AIAA/USU Small Satellite Conference, Logan, UT, 2022.